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ABSTRACT

There is a growing interaction between psychology and education, toward basic research and toward realistic educational events. This is being accompanied by a movement toward equity in education involving the creation of environments for learning that are more adaptive to individual needs than schools generally provide at the present time. Progress is now being made toward the integration required for building a psychology of instruction based on research and theory in learning and cognition. Some of the particular areas discussed include: psychological task analysis of the subject matter of instruction, early childhood education and developmental psychology, the interpretation of intelligence and aptitude in terms of cognitive processes, learning from text and discourse comprehension, behavior modification, and assessment of outcomes of classroom learning. Intensive examples of research on reading and mathematics are discussed in terms of what is known, what is being productively studied, and what is likely to be known in the future that could influence theories of learning and strategies for instruction. (JMF)

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Some Notes About Research on Learning and Schooling*

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1. Relationships Between Research and Practice

Educational practitioners are frequently impatient with the debates that characterize research related to education. Looking for the improvement of their profession and for solutions to school problems, they are struck by the fact that scientists and researchers often disagree with one another. This state of affairs can be given some perspective by examining current disagreement about another social problem--the fight against inflation. Why can't economists agree?¹ Through the news media, their disagreement takes on dramatic proportions. But economists do agree in general on measures to be taken, and disagreement enters when they deal with matters which are tough to implement and affect the activities of people and interest groups in ways that may not be pleasant to consider. These include freer foreign trade, ending feather bedding, closing tax loopholes, removing limits on interest paid to savers, loosening regulation on railroads, airlines, and truckers, and the like. In these contexts, disagreement is often focused on the implementation of proposals on which economists may agree. For example, most economists agree that Congress should cut taxes and that the Federal Reserve should provide cheaper money, but they differ sharply on how big the tax cut should be, how far the government should go in pumping money into the economy, how deep a recession should go to slow down inflation, and how wage-price restraints and credit controls should be used to halt inflation.

Another basis for disagreement among economists results from the fact that inflation is not fully understood. Economists, like other behavioral and social scientists, have worked with far from well-articulated

¹Heller, 1975.

theories. And in this regard, there is intense scientific disagreement and debate. General misinterpretation arises when debate at this level is confused with statements of policy. Policy statements arise from many sources, and researchers act with multiple values, combining what they think they know with divergent evaluations of social priorities, and competing ideas about appropriate implementation. It is difficult to ascertain which policy conclusions come from the economist-as-scientist or the economist-as-citizen.

When we turn to the field of education, the relationship between research and practice appears to be similarly complicated. I do not believe this is so because our knowledge and theory of human learning and performance is less well developed than economic theory. There are a number of areas in which theory and understanding of the phenomena of learning and problem solving are conceptually as strong or stronger than economic theory. But a significant additional problem in education seems to be the "lack of agency." By this I mean that while there exist strong agencies of translation that relate research and practice in many fields, such agencies are still needed in education. Between the physical sciences and practical engineering, between biological sciences and the medical use of drugs and surgical procedures, there exist governmental and industrial developmental agencies that foster the interrelationships and corrective mechanisms necessary between research and practice. In economics, there exist monetary agencies, banking institutions, and federal control agencies that provide this middle ground. Such a middle ground in education is less institutionalized and less well articulated.

Education has some other antecedent idiosyncratic characteristics in relation to the psychological study of learning and human cognition that serve to set the stage for the present. In American education, activities centering around the complex interrelationships involved in translating scientific knowledge into practice and practice into scientific questions have had an erratic history. At the beginning of this century, those great figures concerned with the development of scientific

psychology were enthusiastically encouraging active intercourse between science and its application to education. The work of John Dewey and Edward Thorndike exemplified this close relationship. In his research on the psychology of arithmetic, algebra, and vocabulary development, Thorndike applied his theory of learning directly to the teaching process. Dewey, also a firm advocate of psychological research, thought it most immediately important to move from general concepts of human nature to implementation. It was necessary to provide examples of practice, such as laboratory schools, and demonstrate their feasibility so that others could use them as a basis for further development of new ideas. Dewey envisioned a linking structure between scientific theory and practical application--a conceptual framework in which knowledge from theory and practice could be cumulated and corrected by a two-way interaction.

This spirit of affinity between psychology and education persisted for only a short time after the period of Dewey and Thorndike. Then education and the behavioral sciences went separate ways. A mutual insularity was fostered by activities on both sides. Psychology aspired to become a natural science and take its place among the prestigious sciences, and psychologists went into the laboratory to work out experimental techniques with tasks designed more for theoretical purposes than for their relevance to educational subject matter. Education found its challenges with practitioners and worked to support the professional educational establishment by working with the problems of teaching practices in colleges of education. Psychologists joined the faculties of arts and sciences, and behavioral scientists interested in education joined separate educational psychology departments in schools of education. As a result, the two enterprises took on different characteristics. In the "truly dedicated" departments of behavioral and social sciences, the study of educational processes was not a prestigious or rewarded activity.

It is important to note that the part of psychology alluded to above, generally called experimental psychology--concerned with the study of learning, development, and cognitive performance, was particularly

insulated from assaults of practical concern. In contrast, the techniques and methods of psychological testing and psychometrics developed rapidly during the years just described. The rise of testing practices in the schools and in society has been well documented, but it is important to point out that the testing movement was essentially a technologically oriented enterprise. Theoretical development, with the understanding that it could bring, was little emphasized. Most theoretical work was directed toward statistical prediction of intellectual achievement and not toward the processes that influenced intellectual growth. Individual differences were measured by carefully designed techniques, but the basis of their psychological development and their cognitive properties were little understood.

This recounting of the past serves as a contrast to the present because over the past 15 years, many changes have taken place that redirect psychology and education back to their earlier interaction--but this time with the increased power of a more advanced science. In increasing numbers, psychologists are turning their enterprise to analyses and investigations useful to the study of the instructional process. This trend is apparent in many different fields of psychology, including the study of learning, cognitive performance, human development, social processes, and other areas. There are many reasons for this surge of interest: the increasing prestige that has come from working on socially relevant as well as purely disciplinary problems, the capability of current psychological theory for investigating more complex cognitive behaviors, and the conviction that the interaction between task-oriented and discipline-oriented research can be mutually beneficial for society and for psychological science. For many psychologists interested in educational phenomena, the boundaries between basic and applied research are becoming increasingly blurred. Examination of recent work on the nature and development of human knowledge and intellectual skills makes it apparent that research directed toward educationally relevant areas, including the psychological processes underlying intelligence and aptitude,

can be both highly fundamental in character and, at the same time, directed toward practical understanding. Much exciting work at the moment looks in these two directions--toward basic research and toward realistic educational events. The corrective interactive network between behavioral science and practical education problems envisioned by Dewey appears to be developing.

2. Equity and the Educational Process

Another dimension of today's educational climate is shaping the future. Changes in the educational process--teaching practices, classroom organization, and the management of instruction--are now seen as a necessary condition for the attainment of equal opportunity in the education of children and youth. For the most part, when concern about the equality of educational opportunity is expressed, these process aspects of schooling have been deemphasized. What is emphasized are attempts to change the input to schools through entrance examinations, desegregation procedures, and open admission plans.² Major changes in the outcomes of education have been expected to occur more from selection and placement procedures than from the process of instruction.

The assumption that teaching practices need little change even though significant changes take place in composition and requirements of the student body is an assumption that is no longer viable in today's educational climate. It is increasingly difficult to require that a diverse student population conform to a standardized educational process. The neglect of process change is painfully apparent when admission standards to a college are changed, when competence testing programs are introduced, and when the student population changes in an inner-city high school, and there is no consequent change in the educational programs available. If achievement levels are to be maintained and improved

²Coleman, 1968, 1975; Hawkins, 1977; Mosteller & Moynihan, 1972.

(and our expectations for levels of literacy are higher than ever in our history³), then as input to the system changes or standards change, the process characteristics of the system must also change.

As society places increasing value on reaching out to individual diversity, recognizing cultural pluralism, and improving the scholastic achievement and eventual opportunities of poor children, a major research and development question is how to increase the flexibility of the educational process. The capability of schools to adapt to individual differences by altering instructional procedures and programs needs to be strengthened. If this can be done, then fewer children will be excluded from educational possibilities that encourage their fullest development, and fewer individuals will be required to adjust to a fixed-track environment ill-suited to their requirements for learning and cognitive growth. Multiple opportunities for acquiring knowledge and skill can encourage the use of individual strengths and talents, the development of personal worth, and abilities for problem solving and personal management.

It is necessary to design educational environments that reach out to every person to maximize intellectual and social growth. In particular, poor children deprived of prerequisite opportunities and practice for the learning and coping skills required for schooling can be offered environments in which they have the opportunity to display their knowledge and express their ideas in the course of learning in ways that more advantaged children have already been encouraged to do. A major burden must fall upon the schooling process. The issue of creating environments for learning that are more adaptive to individual needs than schools generally provide at the present time requires focus. At least four aspects will need to be considered:⁴ One, a clear statement is necessary of modern psychological thinking that mandates individualization of the learning process in contrast to older beliefs about

³Resnick & Resnick, 1977.

⁴Glaser, 1977.

learning inherent in present-day teaching practices that foster a selective, relatively inflexible educational process. Two, description is required of the kinds of decisions made about students in various patterns of education that encourage selective or adaptive environments for learning. Three, recommendations need to be forthcoming about how school management and teaching practices can contribute to classroom capabilities for providing more flexible environments for learning. Four, research and development must be directed to assist in the above work so that new knowledge and information about school effectiveness can contribute to the implementation of educational programs that meet the rich variety of student need for learning.

The remainder of these notes about research on learning and schooling concentrate on this fourth activity.

3. Some Current Research Trends

In tandem with and abetting the above developments is the fact that progress is now being made toward the integration required for building a psychology of instruction based on research and theory in learning and cognition. Some of the particular areas that show this interaction include: psychological task analysis of the subject matter of instruction, early childhood education and developmental psychology, the interpretation of intelligence and aptitude in terms of cognitive processes, learning from text and discourse comprehension, behavior modification, and assessment of the outcomes of classroom learning. A brief description of the research in these areas follows, and provides an introduction to the problems that are shaping the field.

- Analysis of the subject matter of instruction. The concepts of modern cognitive theory are being applied to understanding the stages of competence in many domains of knowledge and skill relevant to educational practice, such as text comprehension, mathematical skills and

quantitative reasoning, and solving problems in science. Instructional tasks are being studied by means of sophisticated techniques including simulation, information network analysis, cognitive process models, and learning hierarchies. Using these techniques, careful analysis is being undertaken of what has been learned by an expert in a particular subject-matter domain. What is it that distinguishes a skilled reader from an unskilled one, or a student skilled at mathematics from a less skilled one? Task analysis is being used to describe such differences in terms of the mental operations of experts and novices. These analyses are basic steps in identifying structural units and sequences of instruction that can serve to facilitate the acquisition of knowledge and skill.

Early childhood education and developmental psychology. Psychologists are increasingly involved in educational intervention and compensatory education programs for young children. This movement into the field of education coincides with increased interest in intellectual development and how it might be enhanced through instruction. Overriding theoretical and practical issues continue to be the plasticity of intellectual development, the nature of cultural influences, critical periods of development, and the timing of educational intervention. Key questions concern the general and specific effectiveness of instruction or any deliberate form of intervention in altering or accelerating the biologically and culturally influenced course of intellectual development.

At present, the proliferation of new programs in early childhood education has diminished. One reason for this, among others, is the need to analyze and not merely to implement new ideas. Efforts are now focused on designing methodologies for evaluating effects and on understanding the instructional processes that are involved. Detailed experimental work is being conducted on the levels of competence that define developmental change, and more precise thought is being given to what it might mean to design an educational environment on the basis of principles of cognitive development.

Intelligence, aptitude, and cognitive processes. There is unrest about our current understanding of intelligence and aptitude. A number of factors are involved: (1) The present operational definition of intelligence measurement seems to have reached a plateau of efficiency with our present technology, and the predictive validity of tests has not increased for some time. (2) Since intelligence tests essentially measure general scholastic aptitude, they have not adequately recognized the discontinuity between the background and culture of certain groups in our society and the requirements for succeeding in the conventional educational system. (3) The tests reflect a restrictive view of intelligence that limits the educational system in adapting to students in order to maximize their achievement. In essence, the tests give go/no-go selective decisions, but do not provide much deeper diagnosis for the conduct of education. (4) There is recognition that test theory and technique have not made contact with modern psychological theories of learning and cognition, and that test development should be influenced by new developments in these areas. Modern theory brings us closer to understanding the components of cognitive functioning and can help us succeed in analyzing and understanding the detailed processes underlying intellectual abilities.

These factors are making it necessary and possible for us to understand intelligence and aptitude in more diagnostically useful ways than we have in the past and to change the way in which individual differences might be viewed and assessed for the purposes of education. The nature of the cognitive processes involved in the tasks used to measure and define intelligence is being investigated, and attempts are now being made to assess how they are influenced by cultural background and other experience.

Discourse comprehension. There has been a pronounced increase in the number of studies concerned with meaningful prose materials typical of the kind of material employed in textbooks and everyday written communication. This is in contrast to the more artificial materials of traditional

verbal learning experiments or the specifically designed sentences and short paragraphs of early psycholinguistic studies. The organizational structure of text is being studied as it influences learning, retention, and the comprehension of meaning. These new studies are beginning to address directly the problem of how people learn from text. Investigators are asking how facts are organized by readers, how inferences and conclusions are drawn from written passages, and how to best instruct individuals in text-processing skills.

Study continues on the processes of beginning reading such as letter and word decoding. Accompanying this work, there is an increasing amount of research on the advanced processes involved in comprehending discourse, including the influence of prior knowledge on understanding. Intensive task analysis of the nature of reading comprehension and the increased attention to learning from written materials constitute an exemplary trend in the interaction between research in the behavioral sciences and research on instruction.

Behavior modification. Behavior modification, representing the application of Skinnerian theory and systematic reinforcement contingencies, first appeared in the context of clinical psychology. Educational applications have been burgeoning over the past decade. There are many guidebooks for teachers available, and behavior modification practices are being implemented particularly in elementary schools and in higher education in the form of personalized systems of instruction. The successes and failures of these applications are influencing research. Classroom behavior modification studies are beginning to focus on intellectual performance, extending earlier work primarily focused on decreasing disruptive behavior and increasing attention to task. The cognitive aspects of behavior modification, represented by studies of learning through modeling, of self-reinforcement processes, and of self-regulatory performance in children and adults are of increasing concern.

Assessment of learning outcomes and educational processes. The nature of psychological testing with respect to the measurement of

achievement is now undergoing examination. There are attempts to break away from the classical methods of testing to measurement techniques more concerned with identifying the characteristics of levels of competent performance. Measurement models are being developed for the design of tests that can be interpreted in terms of performance criteria rather than in terms of relative norms. The general goal is to more closely articulate assessment with the conduct of instruction so that constantly updated information about a learner's attained capabilities can be used in making educational decisions.

A related active area of investigation is concerned with detailed analyses of the conditions under which learning takes place in school contexts. There is a growing sophistication in the study of classroom processes. Past studies designed to evaluate curriculum innovations attempted to describe school learning by relating the nature of student input to the quality of student output, and only very generally described the processes intervening between the two. In curriculum implementation studies, detailed information was rarely obtained about differences between effective and less effective classroom processes in terms of some model of classroom instruction. Models now are being developed that attempt to explain the variation obtained in achievement measures in terms of the initial ability of the student, classroom process variables, and the interaction between the two. Of particular interest is use of new methodological procedures for causal analyses (such as path analyses). There is also the strong possibility that research on the dimensions of classroom instructional processes can be related to underlying psychological theories of the acquisition of competence in the subject matters of schooling. Each of these endeavors--classroom research and basic research on learning--should be able to reinforce or challenge the findings of the other.

4. Reading and Mathematics

In this section, as intensive examples of research on school subjects, the investigation of reading and mathematics is discussed in terms of what is known, what is being productively studied, and what is likely to be known in the future that could influence theories of learning and strategies for instruction.

4.1 Reading and the Comprehension of Text

The early stages of learning to read have been carefully investigated in both laboratory and classroom settings. A good deal is known about the psychological processes involved when individuals translate printed symbols into spoken language. Children come into the classroom with skills of a spoken language, and an initial activity in learning to read involves learning the new visual mode of receiving language signals--the process of decoding from print to sound. Enough is known about this process so that we can now move into strong development work. Teaching practices and instructional materials supplied to schools can be analyzed in terms of this available knowledge about the decoding process, and indeed, such work is being carried out.⁵

It is further known that learning to read is also dependent on experience in deriving meaning from written language and in making functional use of the written word. This aspect of learning to read (through using and learning from language) has been less systematically studied than the decoding aspects mentioned above. Debate rages between the relative emphasis of these two aspects of instruction--between emphasis upon a code orientation or language orientation. The evidence is clear that instructional programs with an effective code-oriented approach are advantageous for children who are not facile in this skill, and the advantage has been especially marked for children in compensatory programs. (The tests that show these effects demand relatively unsophisticated

⁵Beck & McCaslin, 1978.

language use and show better performance for those who can recognize printed words accurately and quickly.)

After the primary grades, as expectations for language use become more sophisticated, there is no clear evidence supporting the prior use of either code or language approaches to instruction. There is little, if any, evidence that too much emphasis on code breaking depresses eventual comprehension. Neither is there evidence that once basic coding skills are learned that other reading problems are alleviated. However, there is evidence that coding proficiency and comprehension proficiency are interdependent. If too much mental effort must be invested in decoding, the speed and ease of comprehension is depressed, and at the upper levels of elementary school and high school, poor comprehenders may display word recognition deficiencies that interfere with comprehension.⁶

At present, the debate between code orientation and language orientation appears to be decreasing in recognition of the fact that the competition between the two is an essential aspect of early reading. Learning the code requires a controlled vocabulary, and developing language experience requires a richer language base that matches the child's actual life experiences and understanding. This conflict is now seen as a normal state of affairs around which instruction has to be designed in a systematically effective way. With this knowledge, the problem becomes one of technique and technical development. Teaching practices and materials that appear to solve the problem should be systematically analyzed and studied both to assess their claims and to learn from their art. (The job to be done is not unlike the work of a good tennis pro who must teach basic strokes as well as advanced strategic understanding of the game.) Thus, beginning reading is now largely (not entirely) a development problem that requires work that is difficult, but that is not submerged because of lack of knowledge.

⁶Resnick & Weaver, in press.

On the other hand, lack of knowledge is apparent with respect to the more advanced stages of comprehending information from text and functionally using it in order to learn from it and in order to analyze ideas.⁷ This kind of knowledge has not been as carefully studied as the more "mechanical" aspects of the stages of early reading. But interesting research is being pursued on these upper levels of comprehension, and there is direct concern with the use of written language as a vehicle of thought. In general, the work going on can be characterized in terms of a number of present research themes that are briefly described below.

Comprehension as the construction of knowledge. The first theme reflects a change from viewing comprehension as the storage of knowledge to viewing it as the construction of one's knowledge. Comprehension involves the ability to impose one's present knowledge on the text that one is reading in order to represent it and obtain information from it.⁸ One implication of this concept for future efforts on the teaching of reading is that careful attention needs to be paid to the relationship between an individual's familiarity with the knowledge domain in a reading passage and the influence of this knowledge on developing skills that enable a text to be read and understood. A lack of attention to this relationship is often seen in disparities between elementary reading texts and the world knowledge of a child.

The structure of discourse. A second theme is represented by work on the structure of discourse.⁹ Research of this kind has taught us that there are many patterns of discourse, just as there are many kinds of sentences. The implication of this for the future is that a reading curriculum will need to systematically include the teaching of various discourse forms.

⁷Sticht, et al., 1974.

⁸Anderson, 1976; Bartlett, 1932; Bransford & Franks, 1971; Lenat, 1976; Minsky, 1975; Spillich, et al., in press.

⁹Kintsch, 1977; Mandler & Johnson, 1977; Rumelhart, 1975; van Dijk, 1977.

There are two potential contributions to reading instruction that can follow from the above two research themes. First, as we attend to the relationship between a child's background knowledge and the learning of comprehension skills, we will learn more about the assumed knowledge and forms for communication that come from different cultures. As a result, we should be able to teach to diverse backgrounds and enable children to learn about each other's culture. Secondly, this new research can provide a basis for determining what kinds of skills and forms of discourse are important in reading newspapers, tax forms, history books, instructional manuals, etc. These distinctions can be explicitly taught to individuals so that they can adjust and tune particular reading skills accordingly.

Reading as a multi-component process. The third theme concerns the conception of reading as an activity in which a number of subprocesses must coexist.¹⁰ Each of these processes can vary in terms of the load they place on an individual's memory and mental processing capacity. In order for reading to work, each subprocess must work efficiently so that it does not interfere with the others. For example, the processes concerned with decoding must be efficient enough so that they do not conflict with processes concerned with obtaining meaning from text.¹¹ An implication for this for the future is that a theory of reading should generate specifications for assessing the efficiency that various word-recognition and meaning-generating processes must have if text comprehension is to be effective. A conceivable outcome of this work is that new kinds of diagnostic tests will be developed--tests that assess the speed and efficiency of word processing and the extent to which these skills reach a degree of automaticity that enables comprehension processes to more readily occur.¹²

Reading as the acquisition of a skill. A fourth theme concerns the conception of reading as the long-term acquisition of a skill. As a

¹⁰Frederiksen, 1977; LaBerge & Samuels, 1974; Perfetti & Lesgold, 1977, in press.

¹¹Bobrow & Norman, 1975; Lesgold & Perfetti, 1978; Rumelhart, 1977.

¹²Lesgold, et al., 1978; Resnick & Beck, 1976.

result of current work, an older area in psychology concerned with skill acquisition is being reemphasized. A central question involved is how expertise develops, and what is the nature of expert skill. In the past, educational researchers have emphasized the importance of readiness skills and prerequisites for learning. But they have devoted less attention to understanding expert performance learned over the long term. It appears that we have attended too much to the short run in learning and are now coming to appreciate more fully how much training and practice a major skill requires before high levels of competence are obtained.¹³ The development of skill toward progressively higher levels of expertise often takes longer than we think, and investigation of this problem relates directly to the use of time in a school day and to practice out of school.

Emphasis on the aspects of long-term skill development will probably contribute to cracking the problem of what happens to reading achievement after the second or third grade. Studies show that the effects of better primary curricula disappear for many children in the later years of elementary schooling. Concentration on long-term skill development will probably assist us in learning better what to teach in the third to the eighth grade. Detailed and expensive longitudinal studies will be required to find out why children fall behind and what early reading performance is predictive of future problems. A particularly interesting question for the improvement of teaching is the following: If some children as early as the second grade show normal development of reading ability for familiar overlearned words, but slow development of transfer capabilities for less known words in the context of familiar topics, what particular kinds of skill practice do they require?

4.2 Mathematics Skill and Understanding

- The skill versus understanding debate also has been present in mathematics instruction since early in this century.¹⁴ The debate is

¹³Chi & Glaser, 1978; Larkin, 1977; Simon & Simon, 1978.

¹⁴Brownell, 1928.

characterized by a polarity and tension between the learning of computational algorithms and problem-solving skills on the one hand, and emphasis on "meaningful" instruction and mathematical "understanding" on the other. In recent years, the work on computation has been influenced by research on computer instructional systems that seek to provide maximally effective drill and practice programs. The work on meaningful instruction derives in large part from the influence of Piaget and from the Woods Hole and Cambridge conferences that led to recommendations for teaching the conceptual structures of the discipline of mathematics as a foundation of understanding. These influences contributed to the curriculum reform of the 1960s and the label "new math."

Today, the skill versus understanding debate appears to be active again as evidenced by the concern over the effects of the new math curricula (which may, in reality, be a concern for how well these curricula have been implemented), and the "back-to-basics" movement (although this movement has many different meanings). Currently also, the interrelationship between procedural computational skills and mathematical understanding is an active research area in the study of human cognition.

Mathematics educators have, in general, been an alert and active profession, constantly concerned with new developments that could be applied to their work. For example, the mathematics profession was one of the first to utilize and assess recent forms of individualized instruction, the basic characteristics of which are now found in numerous experimental and commercial programs. A 1975 report by the National Advisory Committee on Mathematical Education presents an overview and analysis of K through 12 school mathematics. This report considers the implications of mathematics curriculum reform over the past 20 years including the influence of new media, patterns of instruction, teacher education, and results and trends in evaluation and assessment. The report also recommends needed research and development including the identification of teaching competencies and the organization of teaching, teacher preparation, the use of calculators and computers, detailed information about classroom

practices, new methods of measuring achievement, large-scale assessment, and certain curriculum modernization involving probability, statistics, metrics, quantitative modeling, etc.

One recommendation in the report identifies a special need: "little is known about the effective, optimal balance or interaction of informal and rigorous modes of expression in learning mathematics and its relationship to content, student ability, and experience" (p. 144). Implicit in this quote and other statements in the report is a recognition of the need for research on mathematics learning and on the nature of mathematics as a human cognitive performance. This requirement can be juxtaposed with recent research developments on the nature of mathematical knowledge and problem solving, and on how skill and understanding in mathematics are acquired. Investigations are being carried out in the fields of cognitive psychology, computer simulation, artificial intelligence, and information processing. Many scientists in these various fields now see the field of mathematics, because of its relatively more structured and transparent content, as a domain in which their work will be able to make strong contributions to instruction.¹⁵

Computation and problem-solving skills are being investigated with the new concepts and methods that are available for analyzing the nature of cognitive processes in detail.¹⁶ This work indicates that a student's proficiency in these skills involves sophisticated cognitive strategies in addition to components of performance that are easily recognized and explicitly taught. Detailed analyses of problem solving in geometry have indicated that three kinds of knowledge are involved: (1) knowledge for pattern recognition, i.e., being able to identify the similarities and differences between geometric objects, e.g., points, line segments, angles, etc.; (2) knowledge of the propositions used to make inferences and to prove theorems, e.g., "corresponding angles are

¹⁵Anderson, 1976; Greeno, 1978; Norman & Rumelhart, 1975; Shank & Abelson, 1977.

¹⁶Brown & Burton, 1978; Gelman & Gallistel, 1978; Newell & Simon, 1972.

congruent," "the sum of the angles of a triangle is 180 degrees"; and (3) strategic knowledge involved in using the above information in order to set goals and form plans and, in general, to organize the individual's activity on the problem that produces a solution.¹⁷

In the context of classroom instruction, in teaching and in textbooks, the first two kinds of knowledge mentioned above are explicitly taught, but the third is not. The first kind of knowledge, required for recognizing the pattern of geometric objects, is a skill that is usually instructed with diagrams and exercises that give practice in identifying the visual features and relationships that students need to perceive. The second kind of knowledge, propositions used in making inferences during problem solving, is also communicated through explicit instruction in the classroom and in textbooks. The third kind of knowledge, strategies used in setting goals and formulating plans, is not explicitly a part of instruction in the content of geometry. This strategic knowledge is generally relegated to the student's general ability (or intelligence) to apply the knowledge that is actually taught.

An alternate view is that all three forms of knowledge--pattern recognition, knowledge of propositions, and strategic problem solving--can be explicitly taught. The strategic knowledge needed for problem solving can be learned and should be considered as a form of knowledge, i.e., knowing a procedural skill. If this is indeed the case, then a problem for instructional research is to investigate ways in which these procedural problem-solving skills can be taught so that they are not fostered only in students who are able to readily induce them. Research of this kind is now seen as an important aspect of mathematics instruction and the study of problem solving. It also seems that excellent teachers, by virtue of the way in which they select and organize examples and problems in their teaching, have implicit systematic ways of teaching problem-solving skills. This expertise should be studied in detail so that it can be specified and generally transmitted to others.

¹⁷Greeno, 1978.

With respect to the basic skills of computation, the general belief that "practice makes perfect" needs to be carefully examined. This belief is true only insofar that practice is necessary, but not sufficient for developing skills. Children can practice errors and misconceptions, or practice in ways that do not produce advances in skillful organized performance. Many errors that occur do so not because of a simple lack of knowledge or inattention on the part of the child, but rather because of sensible misconceptions or incorrect procedural algorithms for computation and problem solving. With this in mind, current research effort is being devoted to the study and development of sophisticated diagnostic materials for finding "bugs" and misconceptions in children's knowledge that do more than test for correct or incorrect outcomes. Work of this kind will assist teachers in becoming aware of children's systematic bases for errors that can be taken into account in getting them to the next stage of learning.¹⁸

Another major policy recommendation of the National Advisory Committee on Mathematics Education, called "anti-dichotomy," states that "in the creation, introduction, and support of mathematics programs, neither teachers, educational administrators, parents, nor the general public should allow themselves to be manipulated into false choices between the old and the new in mathematics, skills and concepts, structure and problem solving. . . . The core of every mathematics program should contain the judicious combination of both elements of each pair with appropriate balance determined by the nature and goals of a program. Little is communicated by the polarization of issues." The report proposes limiting the term "new math" to the developments during the period 1955 to 1975.

In the context of this recommendation, it should be pointed out that the distinction between procedural computational skills and the understanding of mathematical concepts is undergoing careful study.

¹⁸Brown & Burton, 1978.

This distinction cannot be legislated away by saying that it is a false dichotomy. What is required is understanding the relationships between these two forms of knowledge. At the present time, work in cognitive psychology and artificial intelligence is developing new insights into this problem. If these investigations are successful, then it should be possible to override the debate on the skill-versus-understanding issue. The ways in which the two domains of knowledge reinforce and facilitate each other will be made more explicit so that relevant understanding and skill in mathematical procedures can be more properly balanced in school programs.

Brief Notes on Selected Areas of Research

5.1 Intelligence and Aptitude

As indicated earlier, research and development on intelligence and aptitude primarily has taken the form of technological development designed to serve particular patterns of schooling. Current tests of general intelligence and measures of specific aptitude predict school and job success to a moderate but statistically significant extent. These tests, that earlier in our country's history served the cause of democratizing access to schooling, are no longer sufficient to serve the values of a pluralistic society. They do not provide sufficient information for adapting educational experiences to an individual's background and cognitive strengths in order to maximize his or her school attainments. The realization of this deficiency has resulted in stop-gap measures such as the suspension of standardized testing, the attempt at quick design of diagnostic assessment instruments, and changes in selection and entrance procedures. Many of these immediate measures can be successful if and only if there are accompanying changes in patterns of education. For example, it is difficult to see any significant accomplishments resulting from relaxing the entrance requirements to a college or mainstreaming access of "learning disabled"

children to a classroom without making the instructional process more flexible so that the time and tactics of instruction can be varied for different individuals. Research and analysis is required along these lines at the level of school management and teaching process.

A related basic research venture currently in progress is concerned with analyzing the performances assessed by tests of aptitude and intelligence that relate to the ability to learn from schooling.¹⁹ If we can understand more fully the cognitive processes involved in the empirical correlations between measures of aptitude and school success, then this information should be useful for improving the ability of individuals to profit from educational programs. This knowledge should also indicate how schooling can take account of these individual differences.

5.2 Classroom Practices and Macro-Instructional Processes

There is increasingly sophisticated research appearing on the effects of schooling and classroom practices. This seems to be a reaction to large-scale surveys and evaluation studies which only compared mean scores of schools or classrooms on one program to mean scores on another without providing sufficient information about the features of each program that may affect learning. Structural models that link student characteristics, classroom processes, and student attainment are being developed that serve to give direction to studies of school practices. These models can provide cumulative networks in which information obtained can be organized and revised, and inconsistencies examined. This work is being facilitated by the use of new statistical and methodological techniques developed for observational research and field experimentation. In the past, most methodological development in experimental design was devoted to seeking causal explanations of procedures in controlled laboratory situations. Attention is now being

¹⁹ Carroll, 1976; Hunt, et al., 1973; Pellegrino & Glaser, in press; Sternberg, 1977.

paid to the development of techniques of causal analysis that apply more directly to school variables and the allocation of educational effort.²⁰

Work along the above lines is defining systematically the details of important dimensions of classroom instruction such as the use of learning time. What is being studied are no longer poorly defined and implemented innovation models, but rather the aspects of these models that contribute to classroom effectiveness. These analyses provide information for further implementation decisions and also contribute knowledge to potential theories of classroom teaching practices.

The development to be anticipated is a growing macro-theory of teaching and instruction, "macro" in the sense that it is concerned with the large practical variables dealt with in schools such as the allocation and efficient use of time, the structure of the classroom, the nature of teacher feedback and reinforcement to the student, the organizational pattern of teacher-student interaction, the relationship between what is taught and what is assessed, the degree of classroom flexibility required for adapting to learner background, and the details of curriculum materials as this relates to teaching practice and achievement. Such variables need to be part of a theory of teaching in the same way the large variables of economic theory are applied to economic change. As theory at this level develops, it will be undergirded by the more micro-studies of human thinking, problem solving, and the learning of school subjects. In the future, the two levels, macro- and micro-investigations, will become increasingly articulated in studies of classroom learning and the development of human cognition.

5.3 Measuring Achievement and Competence

Questions about achievement testing are arising from all sides. How are standardized achievement tests to be used for assessing competence? What do grade-level scores tell us about a child's performance

²⁰ Bloom, 1976; Carroll, 1963; Cooley, 1978; Cooley & Leinhardt, 1975; Wiley & Harnischfeger, 1974.

that can be used to make instructional decisions? What does it mean, in terms of demonstrated competence, when a child progresses from a grade-level score of 6 to 6.8, and what is the practical significance of this difference? How are achievement tests actually used in schools to guide instructional and administrative decisions? How is the measurement of achievement related to demands for standards in society and what will be the impact of this upon schooling? These questions are being responded to in several ways: First, by the development of programs of assessment and competency-based testing with, hopefully, reasonably long-term study of the effective design and implementation of such programs and their impact on instruction and school management; secondly, studies on the uses of testing in schools by teachers, administrators, and school boards, and how these uses have affected the climate and process of schooling and its social consequences.

A third response concerns the theory and technology of achievement measurement. What we know about best is the technology of designing tests for the prediction of success in school. Our well-developed test theory and its attendant statistical techniques for assessing reliability, validity, etc., has been worked out primarily for the construction of tests used for selective purposes. The theory of achievement testing and techniques for the measurement of attained knowledge and the outcomes of instruction are less well developed.

In its initial conception, the notion of "criterion-referenced testing" was an attempt to alert the educational and psychometric community to the need for further developing basic concepts and procedures for measures of human performance that could directly assist teaching practices. Confusion in the area of criterion-referenced testing has arisen to a large extent because of the attempt to use concepts and techniques developed for other purposes for work on the measurement of learning. It is one task to design a test for the purposes of predicting criterion performance, but a different task to develop adequate measures of criterion performance itself. (Indeed, the identification

and measurement of effective performance criterion for selection test validation has been a persistent problem that is related to the analysis of subject-matter tasks mentioned earlier). In the future, it is to be anticipated that research on the development of performance measures and related research on stages of knowledge development will contribute to new practices for assessing competence. These practices should result in information that is more indicative of attained individual abilities, and thereby facilitate the more informed guidance of learning.

5.4 Residuals of Innovation

A problem in educational innovation is the assessment of indirect effects even when strong direct effects are not found. It is frequently the case that school communities sensibly incorporate elements of innovation in indirect ways. For example, as a result of the work on individualized instruction over the past 15 years, the basic characteristics of individualized programs are now found, at all levels of education, in numerous experimental and commercial programs which teachers find readily acceptable.

The general point to be made in this regard is that research is required on the residual effects of many innovations that have occurred. Teachers and school administrators are often good filters of innovation and tend to incorporate (up to the limits of their resources, time constraints, and other restrictions) useful ideas of teaching practice. Careful study of the residuals of innovative programs that remain in schools, and concepts and patterns of instruction that have been accepted and rejected merit careful analysis as a possibly rich source of information for further educational improvement.²¹

5.5 Theories of Management Decision Making

An important area of research is management decision making including the effective utilization and allocation of school resources.

²¹ Mitroff & Boston, 1977.

Serious treatises have been written with respect to decision-making theory in industrial firms. A recent Nobel prize was awarded for this work, and the study of decision making in educational systems deserves equally serious treatment.

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